SELECTED PROBLEMS REGARDING THE FORMATION OF A SIMULATION MODEL

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 Flight Testing Technology: Reliability of Results Derived from
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16. Abstract

Selected problems in the formation of simulation models are presented. The construction of a flight control system for a V/STOL aircraft simulator is used as the example. Sources of errors in the construction of the system are explained. Diagrams of typical systems are provided. Graphs of response curves and a table of performance data are included.

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For judging the value and the success of a simulation during   /67*
the development and testing of an airplane the question regarding
its validity is of central importance. Which, however, are the
most essential factors that affect validity.

As a first item, I would like to mention the mathematical
simulation model which represents the dynamic properties of the
airplane in the computer. Just as important, however, is the
equipment of the simulator which represents the behavior of the
airplane to the pilot. Added to this is the agreement of simula-
tion problem and flight problem and the familiarity of the pilot
with the simulator. We will discuss here only the simulation
model.

One of the constantly recurring problems of simulation of an
airplane in the development stage is the fact that an accurate
knowledge of the behavior of subsystems is not available at an
early enough date. Of necessity, the formation of simulation
models is resorted to early; later on, they will have to be adapted
step by step to the behavior of actual parts. While performing
this job, many times errors of abstraction are detected that had
been made during the construction of the simulation models;
their effect on simulation results can be studied subsequent to
correction.

This will be demonstrated using simulations for elevator
controllability of VAK 191 B in hovering flight. On one occasion,

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* Numbers in the margin indicate pagination in the foreign text.

a mathematical model for the control of the lift engine and on
another, the VAK ground testing bench with the actual control
were incorporated.

Fig. 1 shows the control of the two lift engine. The FCU's
of the power plants are actuated by the lift engine-power control
lever by way of rods and cables. Cable forces appear at the
FCU's during actuation. A slack is created in the power control
lever as a result of the elasticity in the airframe, the trans-
mission over cam disks, which have been omitted in the drawing for
reasons of clarity, and the many guide points. In the simulation
model a slack between the power control lever and FCU was also
programmed, and the force required for actuation was incorporated
in the simulator by a friction brake at the power control lever.

There are two possible combinations of friction and slack
(Fig. 2). The upper part of the drawing illustrates the case as
it exists in the ground test bench and in the airplane. The pilot
can play with the slack in the power control lever, but will in
any case notice the increase in force when adjusting the FCU's.

In the simulation model for the control of the power plant,
the lower case has been incorporated, which is not in accordance
with actual conditions. This came about as follows:

The simulation engineer, who programmed this model, simulated
the forces required for the actuation of the FCU's simultaneously
with the friction brake, which is installed at the power control
lever in the real cockpit. When measurements of the slack were
available at a later date, the slack was programmed between the
power control lever and the FCU's, an abstraction error that was
uncovered only during simulation with the ground test bench. In
the close fit simulator, the pilot did not notice the slack at
the throttle lever, but only by the reaction of the airplane.

How does the pilot evaluate these different cases? <u>Fig. 3</u> shows a table of these pilot evaluations.

We have gained the following experiences from a comparison of test bench simulation with cockpit simulation.

It is easier to control altitude with the test bench, or phrased differently, pilot evaluation is the same with more slack in the test bench. This means: the calculated slack in the close <u>/69</u> fit simulator can be made smaller than in reality because in free flight the pilot senses the slack and can render it partly ineffective.

However, the lift engines are controlled not only by the pilot but also by the controller, since they are applied for controlling the pitch position.

Fig. 1 shows that with engaged thrust modulation the duplex-servo controlled by the controller actuates a balance beam that shifts the lift engines against one another. Slack was also measured between the duplexservo travel and the FCU's which has an effect on the transition behavior in the pitch phase. <u>Fig. 4</u> shows the difference in the transition behavior in accordance with jump input into the simulation with and without slack.

With programmed slack an overshooting is evident in the jump output, just as it is observed in free flight, and a control output that does not return to zero, due to the fact that the disturbing moment must be compensated for by a bleed moment on account of the lift engines having been shifted within the hysteresis. Altitude controllability is not affected by this slack; forces in this case are irrelevant.

These two examples point up a problem area accompanying the construction model, i.e., only when measurement results from actual

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parts and whole systems of the airplane are available will the
simulation engineer be in a position to form a final simulation
model; it is just effects of actual parts such as slack, friction
and elasticity that cannot be predicted; however, they are often
important because, as in the present case, they can severely
affect controllability.

Another problem area is the design of valid engine models in
which the simulation designer, however, must depend extensively
on the data furnished by the engine manufacturer.

For example, the VAK 191 B has a propulsion system that had   /70
not yet been used operationally, and the manufacturer himself
does not yet have complete mastery over its problems. During
flight testing, part of the data given in the performance speci-
fications turned out to be considerably more favorable. It is very
difficult to constantly adapt the power plant behavior to actual
facts. This is a basic problem, due to the fact that thrust
reacts with great sensitivity to parameter changes in the power
plant components. Power plants of the same type can behave very
differently with respect to their effeciency. Deviations from
design data of components, engine flight hours and, for instance,
a dirty compressor in that connection bring about these causes.
Fig. 5 shows a comparison of throttle response of the simulation
model with measurements on the power plant. Finally, a last
problem area will be shown with an example, i.e., the difficulty
of acquiring data from flight tests for the necessary updating of
the simulation models and the clarification of differences between
results from flight tests and simulations.

We have tried, by means of flight tests, to ascertain the
rolling control acceleration of the VAK 191 B during hovering
flight as a function of the duplexservo travel. To this end, we
proceeded as follows:

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During hovering flight, the pilot gave brief input signals in the axis of roll, while the duplexservo travel as well as the flight position vector were recorded. The angular acceleration $\ddot{\phi}(t)$ of the airplane, formed by way of the duplexservo travel, was plotted by means of differentiating $\dot{\phi}(t)$ (w_y and w_z were zero), and were compared with the specified values.

However, the following points will briefly outline how problematic a quantitative comparison of flight test results with simulation results is:

-- During scanning a discrepancy between position gyro signal and rate gyro signal became evident. Differentiation of the values measured by the position gyro resulted in only 60% of the values measured by the rate gyro. A verification of the gyro signal by means of a flight table uncovered a mismatch of the position gyro /71 and the following repeater.

-- Crosswind conditions, fuel spills, elasticity of airframe, mounting of the gyro case on shock mounts cannot be covered or only very imcompletely.

-- However, a possible asymmetry of the airplane, as for instance, a center of gravity deviation, a thrust difference at the cruise engine, an incorrect bleed nozzle adjustment or an unsymmetrical throughput can also lead to a considerable deviation from all calculated values.

-- Deviations can also occur if the calculated moment of inertia about the longitudinal axis does not agree with that of the airplane, if the thrust and bleed levels are different in the cases being compared or if errors have occurred during the transmission of measured data.

-- Finally, the aerodynamic data can also be at fault.

What is the status of reliability of statements based on simulation in view of these many uncertainties?

In order to clarify this question the following approach seems practicable in this special case; we are at present trying to provide proof of its success.

-- Flying conditions must be selected from flight tests in accordance with the following aspects:

    -- The external disturbing moment is to be constant during the time period to be evaluated.

    -- Thrust of power plants and, therefore, bleed level constant.

    -- Roll nozzle activity, as large and brief as possible /72 by pilot input.

-- The angle of roll acceleration of the airplane is arrived at by differentiation and plotted over the duplexservo travel. A directional field for the control acceleration curve is created; disturbing moments are still unknown.

-- In the case of missing or symmetrical oncoming air flow, the external disturbing moment of roll is assumed to be zero on account of the oncoming air flow against the airplane. A segment of the ordinate of the the roll control acceleration curve to be determined is then a measure of the asymmetry of the airplane.

-- Originating at the ordinate segment, the directional field must be followed and the roll control acceleration curve plotted.

Due to the fact that errors in measuring data pickups and measuring data transmitters are unavoidable, a comparison of results can only be made within a "range of confidence."

This means that, for every flying condition for which a comparison is to be made, the maximum possible measuring and transmitting errors must be determined.

The flying condition in question is varied in simulations so that all possible combinations of the individual independent errors of measurement are taken into account.

The most unfavorable combination of errors of measurement leads to the widest control range in the disturbing moment and is defined as "range of confidence."

As long as the errors of measurement are small the areas of spread can be combined numerically in linearized approximation, and the main effect of the errors of measurement can thus be determined for the respective flying condition.

When the measuring data for all flying conditions representing a flying range are located within the respective "range of confidence" the simulation with respect to roll control acceleration in this flying range is considered as "valid."

In case of deviations, an attempt must be made to come to a conclusion regarding the main effect on the faulty data.

Summary

By way of selected examples it was made clear that in the construction of simulation models it is easy to make abstraction errors, that real-part effects, such as friction, elasticity and

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slack must be covered correctly for certain simulations, and that the proof of validity of simulation models is difficult, even in the presence of flight test results. The only way open for the simulation engineer to answer the question of reliability of his results is the laborious one of assembling the very many individual aspects into a mosaic-like whole.
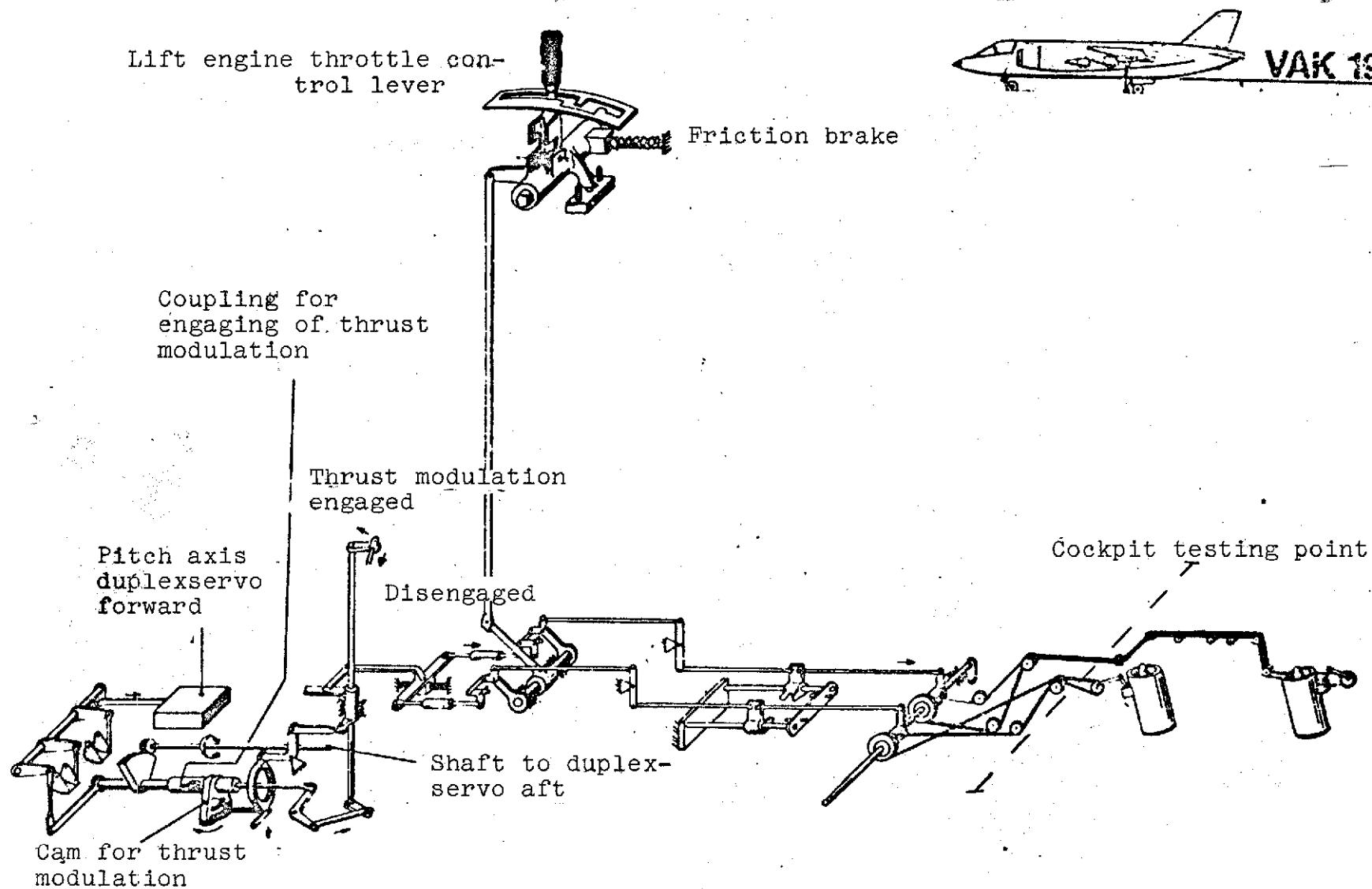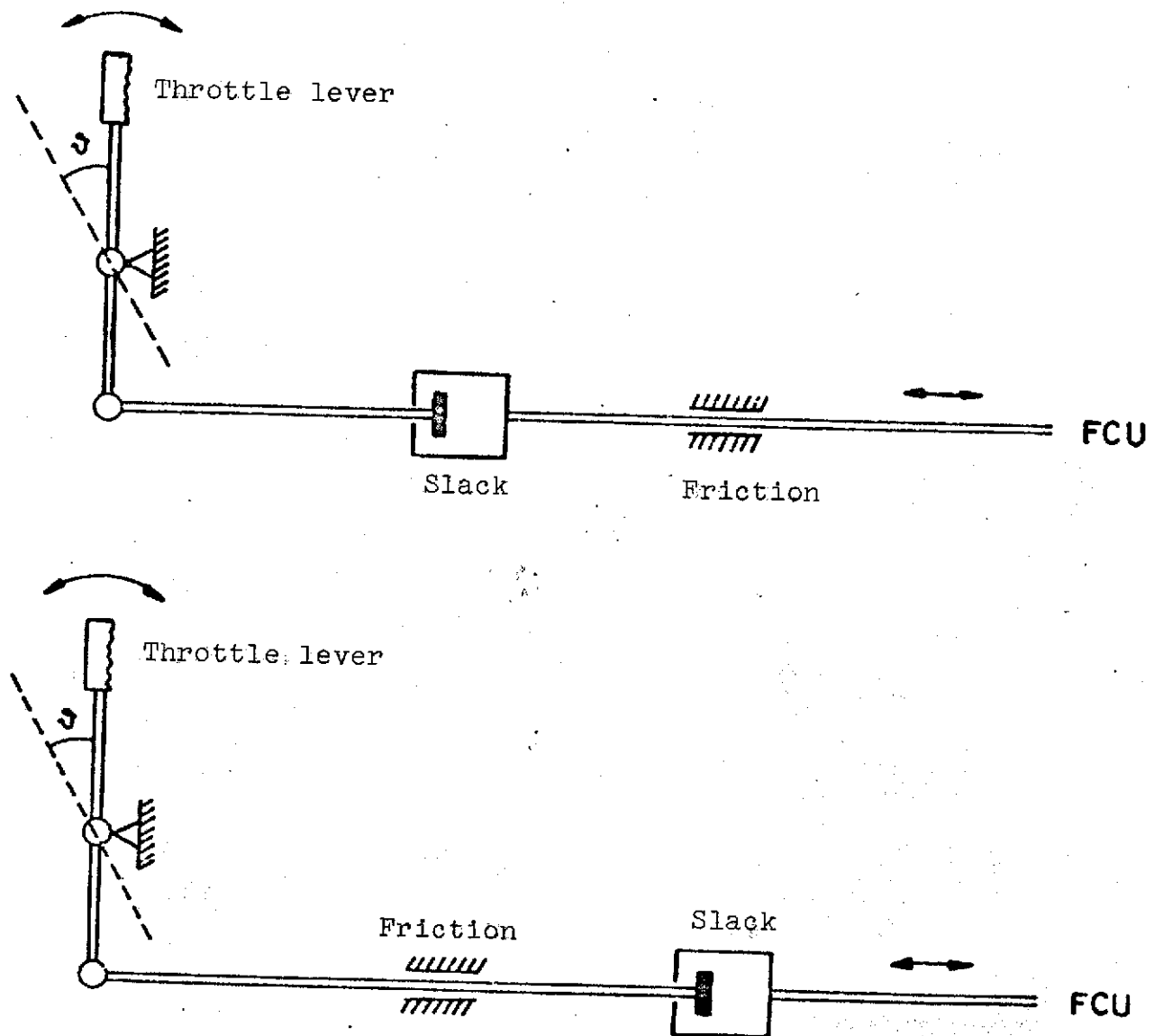
Lift engine throttle control lever

Friction brake

VAK 191 B

Coupling for engaging of thrust modulation

Thrust modulation engaged

Pitch axis duplexservo forward

Disengaged

Cockpit testing point

Shaft to duplexservo aft

Cam for thrust modulation

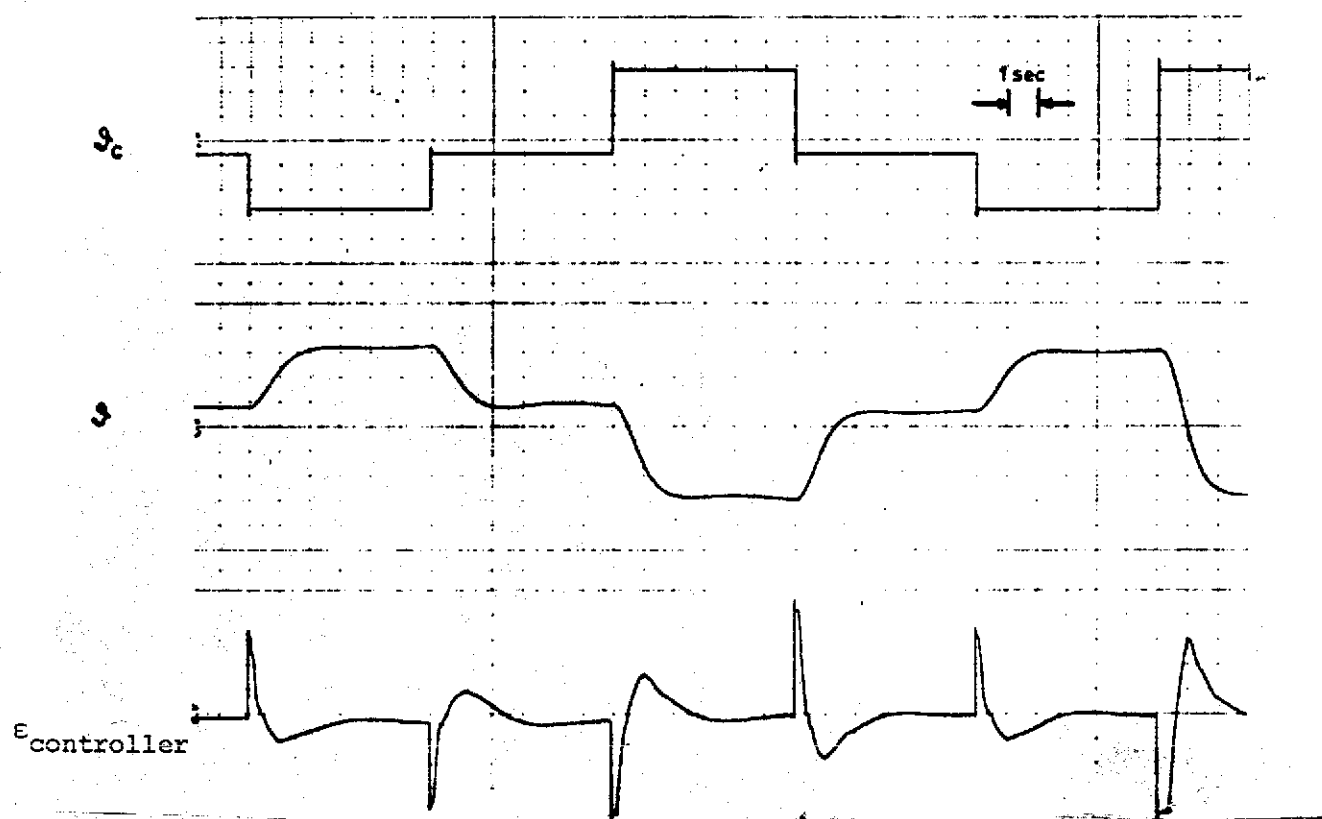Fig. 1. Control of the lift engines.

Fig. 2. Models of power plant control.

Altitude control with	Kind of simulation	Slack in control	Pilot evaluation	Reasons/Remarks
Cruise engine	Cockpit Simulation	0	3	Cruise engine dynamics sluggish, operating forces very slight
	Test bench Simulation	$\pm\ 0.3^{\circ}$	4	Cruise engine dynamics sluggish
Lift engine	Cockpit Simulation	$\pm\ 1^{\circ}$	3	Operating forces improper
		$\pm\ 3^{\circ}$	5	Large overtravel, operating forces improper
	Test bench Simulation	$\pm\ 2^{\circ}$ *	4	Without irreversible unit. Operating forces high, slack a little smaller than in case with irreversible unit; effect of thrust modulation is to use excess pressure
		$\pm\ 4^{\circ}$ *	5	With irreversible unit. Slack well noticeable at operating forces. Forces outside of slack belt very high; constant overtravel.
Lift engine + cruise engine	Cockpit Simulation	$\pm\ 1^{\circ}$	2-3	Operating forces improper
		$\pm\ 3^{\circ}$	4	Overtravel on account of sluggish cruise engine and slack in lift engine control. Operating forces still improper.
	Test bench Simulation	$\pm\ 2^{\circ}$ *	3	Without irreversible unit. Slack with lift power plant less than with irreversible unit. Influence of thrust modulation is towards use of excess pressure.
		$\pm\ 4^{\circ}$ *	4	With irreversible unit. Precision adjustment difficult on account of forces. Forces within slack quite different from forces outside. Constant overtravel.

* The data for hysteresis in test bench simulation are mean values from forward and aft lift engines.

Fig. 3. Table of pilot evaluation.
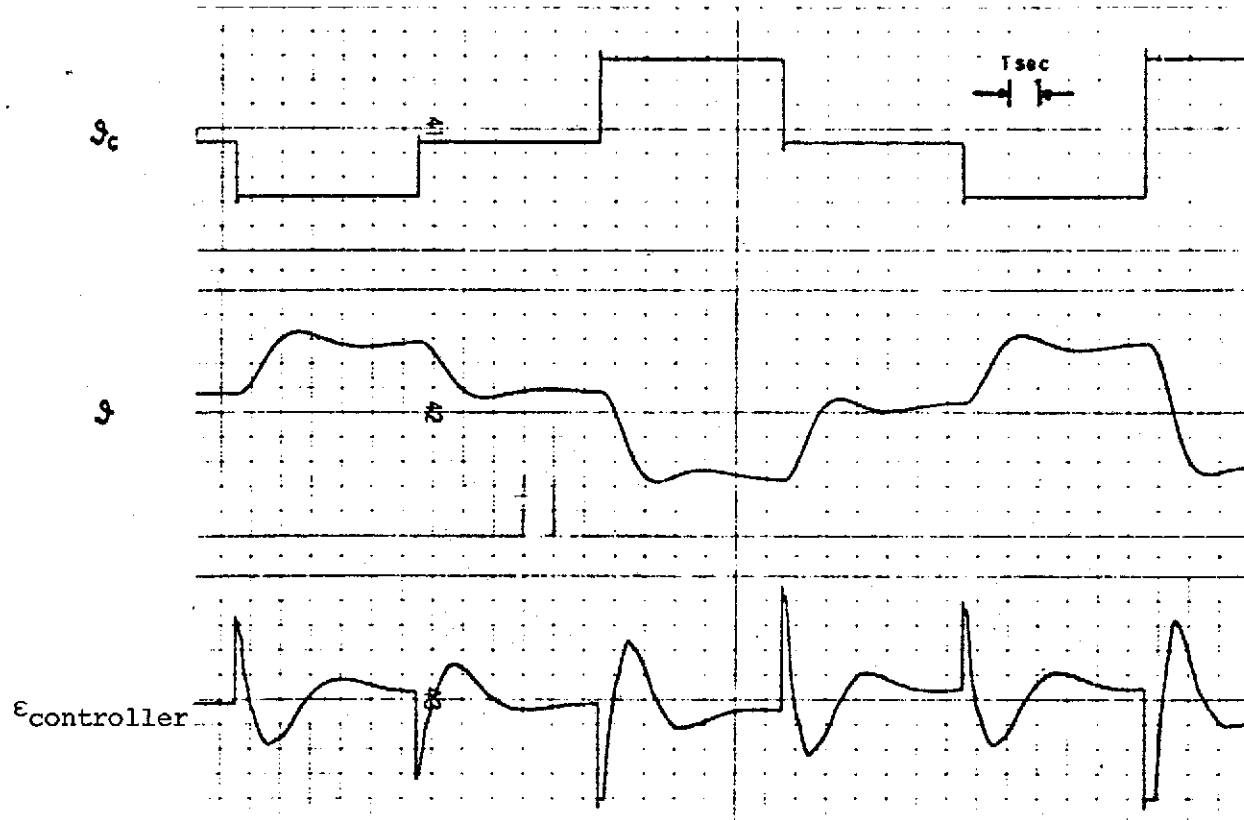
Pitch control behavior with hysteresis in lift engine control

Pitch control behavior with hysteresis in lift engine control
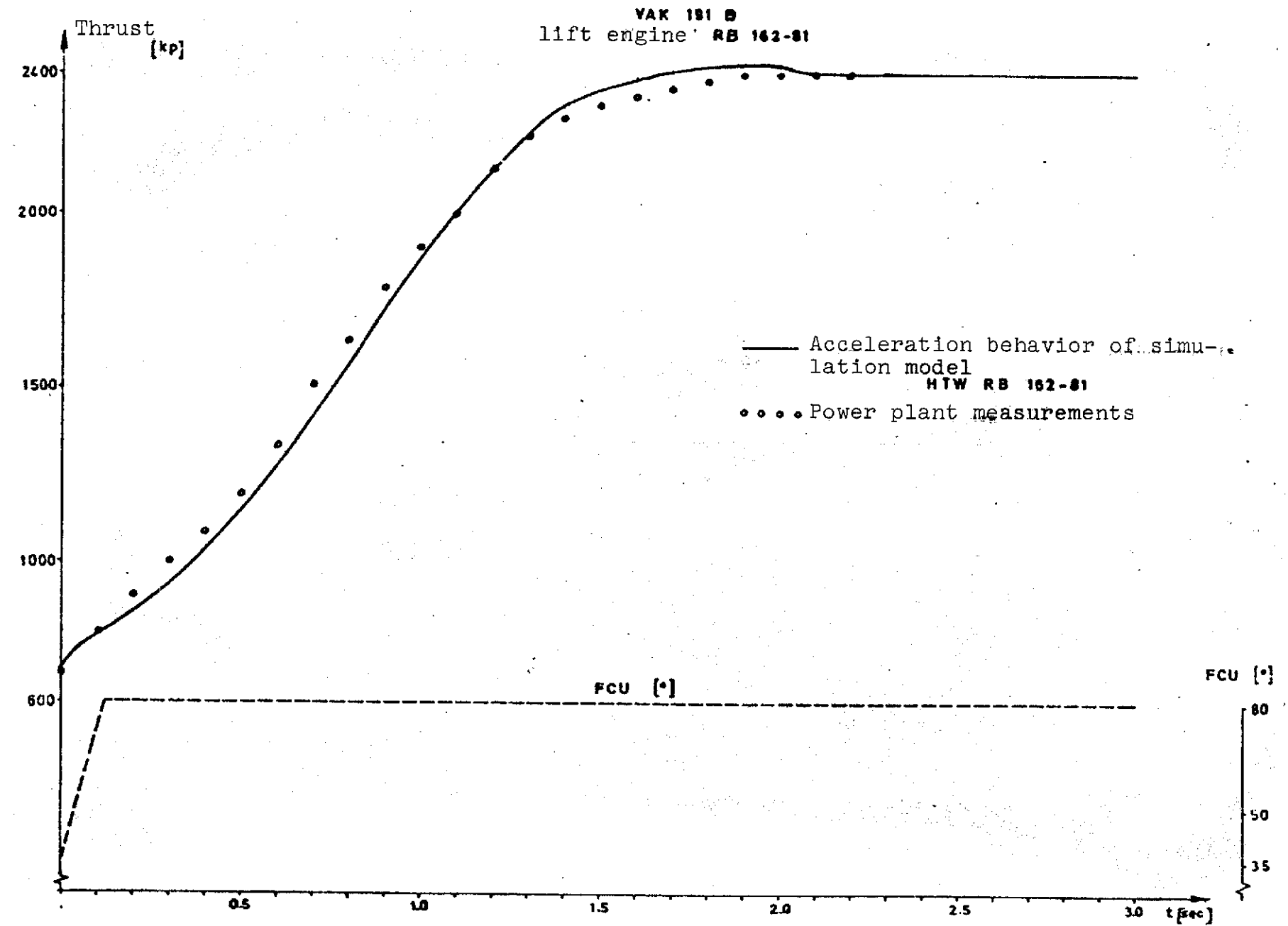
Fig. 4.

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Thrust [kP]

YAK 191 B
lift engine RB 162-81

2400

2000

1500

1000

600

——— Acceleration behavior of simu-
lation model
HTW RB 162-81
∘ ∘ ∘ ∘ Power plant measurements

FCU [°]

FCU [°]

80

50

35

0.5   1.0   1.5   2.0   2.5   3.0   t [sec]

Fig. 5.